

Description

SYSTEM FOR ACTUATING AN ENGINE VALVE

- [01] This application claims the benefit of prior provisional patent application Serial No. 60/422093 filed October 30, 2002.

Technical Field

- [02] The present disclosure is directed to a system for actuating an engine valve and, more particularly, the present disclosure is directed to a system for actuating an engine valve in an internal combustion engine.

Background

- [03] Many vehicles, such as, for example, automobiles, on highway trucks, or off highway trucks, include an internal combustion engine that provides power for the vehicle. A typical internal combustion engine includes a series of intake and exhaust valves that control the flow of gases to and from the combustion chambers of the engine. The engine may also include a valve actuation system, such as, for example, a cam driven valve actuation system to control the actuation timing of the engine valves.
- [04] The overall performance of the internal combustion engine may be improved by using a series of auxiliary valve actuators, such as, for example, hydraulically powered actuators, that actuate the engine valves to selectively implement variations on the conventional, cam-driven valve timing. For example, the auxiliary valve actuators may be used to actuate the exhaust valves of the engine to implement an "engine braking" cycle. In an engine braking cycle, the auxiliary valve actuators open the exhaust valves of the engine when a piston associated with each combustion chamber is at or near a top-dead-center position at the end of a compression stroke. This opening of the exhaust valves allows the air compressed by the piston in the combustion chamber during the

compression stroke to escape from the combustion chamber through an exhaust passageway. In this manner, the pistons of the engine may be selectively used as air compressors to absorb power instead of generating power in response to the combustion of fuel.

[05]                Because the auxiliary valve actuators are used only when the engine is experiencing selected operating conditions, the auxiliary valve actuators should avoid interfering with the operation of the cam driven valve actuation system when the engine is experiencing other operating conditions. The performance of the engine may be negatively impacted if, for example, the auxiliary valve actuators inadvertently open the exhaust valves during the intake stroke of the pistons. This type of interference may occur if the auxiliary valve actuators do not account for changes in the size of engine components due to thermal expansion.

[06]                To prevent any such interference, the auxiliary valve actuators are typically separated from the exhaust valve assembly by a certain distance, which is commonly referred to as a “lash.” The lash is the distance that separates the auxiliary valve actuators from the engine valve assembly. The lash may prevent inadvertent or unintentional opening of the engine valves by the auxiliary valve actuators when changes in temperature of the engine cause a change in size of the engine components.

[07]                As shown in U.S. Patent No. 4,898,128 to Meneely, an auxiliary valve actuator may include a de-lash mechanism to absorb the lash between the auxiliary valve actuator and the valve actuation assembly. Absorbing the lash reduces the amount of time needed by the auxiliary valve actuators to open the respective engine valve. The reduced response time of the auxiliary valve actuators may lead to increased control over the auxiliary valve actuations. However, including a de-lash mechanism with the auxiliary valve actuators increases the cost of the actuators and may lead to additional maintenance.

[08]                   The engine valve actuation system of the present disclosure solves one or more of the problems set forth above.

Summary of the Invention

[09]                   In one aspect, the present disclosure is directed to a system for actuating a valve element in an engine valve assembly of an internal combustion engine. The system has a first piston that includes a first rod and is disposed in a first chamber. The system also includes a second piston that has a second rod with an end that is separated from the engine valve assembly by a predetermined distance. The second piston is disposed in a second chamber that is in fluid connection with the first chamber such that movement of the first piston causes a corresponding movement of the second piston. A cam having a cam lobe is operatively engaged with the first rod such that rotation of the cam and cam lobe moves the first piston to thereby move the second piston. The cam lobe has a shape adapted to cause the second rod to move through the predetermined distance and to engage the engine valve assembly to move the valve element at a predetermined point in the operating cycle of the internal combustion engine.

[10]                   In another aspect, the present disclosure is directed to a method of actuating a valve element in an engine valve assembly of an internal combustion engine. An end of a slave rod connected to a slave piston is positioned a predetermined distance from an engine valve assembly. Fluid is supplied to a fluid line connecting a master piston having a master rod with the slave piston. A cam having a cam lobe operatively engaged with the master rod is rotated to thereby move the master piston and cause a corresponding movement of the slave piston and slave rod. The cam lobe has a shape adapted to move the slave rod through the predetermined distance and to engage the engine valve assembly to move the valve element at a predetermined point in the operating cycle of the internal combustion engine.

### Brief Description of the Drawings

[11] Fig. 1 is a schematic and diagrammatic illustration of a system for actuating an engine valve in accordance with an exemplary embodiment of the present invention; and

[12] Fig. 2 is a graph illustrating exemplary relationships between the crank angle of the engine and the lift of an engine valve.

### Detailed Description

[13] An exemplary embodiment of a system for actuating an engine valve 12 for an internal combustion engine 10 is illustrated in Fig. 1. Engine 10 includes an engine block 16 having a cylinder 17 that defines a combustion chamber 20. Engine block 16 may define a plurality of cylinders 17. A cylinder head 18 may be engaged with engine block 16 to cover each cylinder 17.

[14] As also shown, a piston 14 may be disposed within cylinder 17. Piston 14 is adapted to reciprocate between a bottom-dead-center position and a top-dead-center position within cylinder 17. Piston 14 may be connected to a crankshaft (not shown) such that a rotation of the crankshaft causes piston 14 to reciprocate between the bottom-dead-center position and the top-dead-center position in cylinder 17. In addition, a reciprocating movement of piston 14 between the bottom-dead-center position and the top-dead-center position within cylinder 17 will cause a corresponding rotation of the crankshaft.

[15] Engine 10 may, for example, operate in a conventional four stroke diesel cycle. In a four stroke diesel cycle, piston 14 moves through an intake stroke, a compression stroke, a combustion stroke, and an exhaust stroke. One skilled in the art will recognize that engine 10 may operate in other known operating cycles, such as, for example, an Otto cycle.

[16] Cylinder head 18 may define one or more openings and passageways (not shown) that lead to and from combustion chamber 20. In particular, cylinder head 18 may define an intake passageway that leads to

combustion chamber 20 and an exhaust passageway that leads from combustion chamber 20. Cylinder head 18 may also define one or more intake openings that connect the intake passageway with combustion chamber 20. Cylinder head 18 may also define one or more exhaust openings that connect the exhaust passageway with combustion chamber 20.

[17] One or more engine valves 24 may be operatively engaged with cylinder head 18. Each valve 24 may include a valve stem 26 and a valve element 25. Each valve element 25 is disposed in either an intake opening or an exhaust opening and may be moved between a first position where fluid is prevented from flowing relative to the respective opening and a second position where fluid is allowed to flow relative to the respective opening.

[18] One engine valve 24 may be disposed in each of the intake openings or the exhaust openings defined in cylinder head 18. For example, in an engine 10 having a pair of intake openings and a pair of exhaust openings for each cylinder 17, a pair of engine valves 24 may be disposed in the intake openings and a pair of engine valves 24 may be disposed in the exhaust openings. A bridge 28 may connect each pair of engine valves 24. Bridge 28 allows each pair of engine valves 24 to be actuated in unison.

[19] Each engine valve 24 may include a valve return spring 30. Valve return spring 30 may be disposed between cylinder head 18 and bridge 28. Alternatively, spring 30 may be disposed between cylinder head 18 and another portion of engine valve 24, such as, for example, valve stem 26. Each valve return spring 30 acts to return engine valves 24 to the first position where the flow of fluid relative to the respective opening is blocked.

[20] Engine 10 may include a valve actuation system 32 that actuates engine valves 24. Valve actuation system 32 may be a conventional cam-driven system that includes a cam-driven rocker arm 34. Rotation of the cam (not shown) causes rocker arm 34 to pivot and thereby move engine valves 24 towards the second position to allow a flow of fluid relative to the respective opening.

One skilled in the art will recognize, however, that the valve actuation system may be another type of system, such as, for example, a hydraulically driven system or an electrically driven system.

[21] Valve actuation system 32 may be adapted to coordinate the opening of engine valves 24 with the movement of piston 14. For example, valve actuation system 32 may open the exhaust valves when piston 14 is moving through an exhaust stroke. In this manner, exhaust gases created during the combustion of fuel in combustion chamber 20 may be exhausted from combustion chamber 20 through the exhaust passageway.

[22] Engine 10 may also include a fuel injection system 36. Fuel injection system 36 may include a cam 40 having a cam lobe 42. A cam follower 46 may be engaged with an outer surface 44 of cam lobe 42. Cam follower 46 may be connected to a rocker arm 38 that is operatively engaged with a fuel injector (not shown).

[23] Rotation of cam 40 and cam lobe 42 causes cam follower 46 to reciprocate based on the shape of outer surface 44. The motion of cam follower 46 causes rocker arm 38 to pivot to thereby activate the fuel injector to deliver a certain quantity of fuel, which may be, for example, diesel fuel, gasoline, or natural gas, to combustion chamber 20. Cam 40 and cam lobe 42 may be shaped to drive rocker arm 38 through a pivoting motion that causes the fuel injector to inject a certain quantity of fuel into combustion chamber 20 at a certain point in the operating cycle of engine 10. For example, fuel injection system 36 may inject a quantity of diesel fuel into combustion chamber 20 as piston 14 moves from a bottom-dead-center position towards a top-dead-center position during a compression stroke.

[24] A system 12 for selectively actuating engine valves 24 may be engaged with engine 10. System 12 may include a first piston 48, which may be referred to as a "master piston," and a second piston 58, which may be referred to as a "slave piston." First piston 48 is disposed in a housing 50 to define a master

chamber 54 and second piston 58 is disposed in a housing 60 to define a slave chamber 64.

[25] A first rod 49 is connected to first piston 48 to move with first piston 48. First rod 49 may be disposed adjacent rocker arm 38 of fuel injection system 36. A piston spring 52 may be disposed within chamber 50 to act on first piston 48 to bias first rod 49 away from rocker arm 38.

[26] A second rod 59 may be connected to second piston 58 to move with second piston 58. Second rod 59 may be disposed adjacent rocker arm 34 of valve actuation system 32. A piston spring 62 may be disposed between housing 60 and piston 58 to bias second rod 59 away from rocker arm 34. An end 61 of second rod 59 may be separated from rocker arm 34 of valve actuation system 32 by a distance,  $x$ , which may be referred to as the “lash” or the “lash distance.”

[27] A fluid line 56 provides a fluid connection between master chamber 54 and slave chamber 64. The introduction of pressurized fluid into master chamber 54 moves first piston 48 to compress piston spring 52. When piston spring 52 is compressed, first rod 49 extends towards rocker arm 38 of fuel injection system 36.

[28] When rocker arm 38 moves in response to rotation of cam 40 and cam lobe 42, rocker arm 38 engages first rod 49 to move first piston 48 within housing 50. The movement of first piston 48 within housing 50 forces fluid from master chamber 54 through fluid line 56 to slave chamber 64. The introduction of the fluid into slave chamber 64 causes second piston 58 to move within housing 60. As second piston 58 moves within housing 50, second rod 59 moves through distance,  $x$ , and engages rocker arm 34 to move engine valves 24 towards the second position.

[29] An adjustment mechanism 65 may be operatively engaged with second piston 58 or housing 60. Adjustment mechanism 65 may be any mechanism readily apparent to one skilled in the art that allows the position of second rod 59 relative to rocker arm 34 to be changed. In this manner, the

distance,  $x$ , may be controlled or adjusted as necessary. Adjustment mechanism 65 may be mechanically controlled, such as, for example, by a threaded connection or a ball and detent device. Alternatively, adjustment mechanism 65 may be controlled automatically in response to a signal, such as, for example, through an electronic or hydraulic device.

[30] As explained in greater detail below, the graph 90 of Fig. 2 illustrates the effect of adjusting the distance,  $x$ , between end 61 of second rod 59 and rocker arm 34 (referring to Fig. 1) on the relationship between engine crank angle and engine valve lift. Line 92 represents the lift of engine valve 24 when the lash distance,  $x$ , is approximately 0. Line 94 represents the lift of engine valve 24 when the lash distance,  $x$ , is approximately 1 mm (0.04 in.).

[31] As shown in Fig. 1, a fluid supply system 66 may be adapted to supply fluid to fluid line 56 and to master and slave chambers 54 and 64, respectively. Fluid supply system 66 includes a pump 70 that draws an operating fluid, which may be, for example, a lubricating oil, from a tank 68 through a fluid line 76. Pump 70 increases the pressure of the operating fluid and directs the pressurized fluid through a fluid line 77 into gallery 72. Gallery 72 may be, for example, part of a lubrication system associated with engine 10.

[32] Gallery 72 is connected to system 12 through fluid lines 78 and 82. A check valve 86 may be disposed between fluid line 82 and fluid line 56. Check valve 86 is adapted to prevent a reverse flow of fluid from fluid line 56 to fluid line 82.

[33] A fluid return line 80 may provide a fluid connection between fluid line 56 and tank 68. Alternatively, fluid return line 80 may connect fluid line 56 with fluid line 76 at or near the inlet to pump 70. Fluid return line 80 allows fluid to exit system 12.

[34] A control valve 74 controls the flow of fluid to and from system 12. Control valve 74 has a first position (as illustrated in Fig. 1) where fluid is allowed to flow from gallery 72 to fluid line 86 and where fluid return line 80 is



blocked. Control valve 74 has a second position where fluid is prevented from flowing from gallery 72 to fluid line 86 and where fluid is allowed to flow from system 12 through fluid return line 80. Control valve 74 may be any type of valve or combination of valves that allow the flow of fluid to and from system 12 to be controlled in this manner.

- [35] As mentioned previously, engine 10 may include multiple cylinders 17 and combustion chambers 20. A similar system 12 may be provided to actuate the engine valves 24 associated with each cylinder 17. Fluid line 82 may branch into one or more fluid lines 84 to provide fluid for each such system 12. Each fluid line 84 may include a check valve 88 to prevent a reverse flow of fluid through control valve 74. A fluid return line 85 may provide a fluid path through which fluid returns to tank 68 from the additional system 12. All systems 12 for engine 10 may be controlled by a single control valve 74. Alternatively, a series of control valves 74 may be used to control each system 12 on engine 10.

#### Industrial Applicability

- [36] Engine 10 may be operated to provide power to propel a vehicle, such as, for example, an automobile, an on highway truck, or an off highway truck. Engine 10 may include a series of cylinders 17 and pistons 14 that are operated in a conventional four stroke diesel cycle. For the purposes of the present disclosure, the operation of a single cylinder 17 of engine 10 will be described.
- [37] During a conventional operating cycle of engine 10, piston 14 moves from a top-dead-center position towards a bottom-dead-center position in an intake stroke. As piston 14 moves through the intake stroke, engine valve actuation system 32 opens the intake valves associated with combustion chamber 20. The opening of the intake valves allows intake air to flow into combustion chamber 20. The intake air may be at ambient pressure or the intake air may be pressurized such as, for example, by a turbocharger.

- [38]                   Piston 14 then moves from the bottom-dead-center position towards the top-dead-center position of a combustion stroke. Fuel injection system 32 may inject a quantity of fuel into the combustion chamber 20. The fuel mixes with the intake air to form a combustible mixture. The movement of piston 14 towards the top-dead-center position within combustion chamber 20 compresses the air and fuel mixture. Engine 10 may be adapted so that piston 14 compresses the air and fuel mixture to reach the critical, or combustion, pressure when piston 14 is at or near the top-dead-center position of the compression stroke.
- [39]                   When the fuel and air mixture reaches the ignition pressure, the fuel ignites and the mixture is combusted. The combustion of the fuel and air mixture drives piston 14 towards the bottom-dead-center position in a combustion stroke. The driving power of the fuel combustion is translated into an output rotation of a crankshaft (not shown) that is used to propel the vehicle.
- [40]                   Piston 14 then returns from the bottom-dead-center position to the top-dead-center position in an exhaust stroke. During the exhaust stroke, engine valve actuation system moves the exhaust valves 24 towards the second position to create a fluid passageway from combustion chamber 20 to the exhaust passageway. The movement of piston 14 towards the top-dead-center position forces combustion exhaust from combustion chamber 20 into exhaust passageway 22. The operating cycle of piston 14 may then begin again with another intake stroke.
- [41]                   System 12 may be used to selectively implement a variation on the conventional valve timing of the intake or exhaust valves. For the purposes of the present disclosure, the implementation of an “engine braking” cycle will be described. One skilled in the art will recognize that system 12 may be used to selectively implement other variations on conventional valve timing, such as, for example, a Miller cycle.

- [42]                    During selected engine or vehicle operating conditions, such as, for example, when a vehicle operator provides an instruction to decelerate the vehicle, the engine may operate in an “engine braking” mode. To initiate the “engine braking” mode, control valve 74 is energized to move control valve 74 to the first position (as illustrated in Fig. 1). When control valve 74 is in the first position, fluid flows from gallery 72 into system through fluid line 56.
- [43]                    The introduction of fluid into system 12 activates the “engine braking” mode. The fluid causes first piston 48 to move within housing 50 to compress piston spring 52. First rod 49 extends into position adjacent rocker arm 38 of fuel injection system 36.
- [44]                    Cam 40 and cam lobe 42 of fuel injection system 36 rotate to move cam follower 46 and cause rocker arm 38 to pivot. Rocker arm 38 engages first rod 49 to move first piston 48 within housing 50. The movement of first piston 48 forces fluid out of master chamber 54 and through fluid line 56. Check valve 86 prevents fluid from escaping from fluid line 56. In this manner, a hydraulic link is formed between first and second pistons 48 and 58. With the hydraulic link, any movement of first piston 48 causes a corresponding movement of second piston 58. Thus, as first piston 48 moves in response to the shape of cam 40 and cam lobe 42, second piston 58 moves towards engine valve assembly 32. End 61 of second rod 59 moves through distance,  $x$ , until end 61 engages rocker arm 34. Continued movement of first and second pistons 48 and 58 cause second rod 59 to move rocker arm 34 and thereby move valve elements 25 towards the second position to allow a flow of fluid from combustion chamber 20.
- [45]                    As cam 40 and cam lobe 42 continue to rotate, rocker arm 38 of fuel injection system 36 will be allowed to pivot back to its starting position. The force of valve return springs 30 act through rocker arm 34 and second rod 59 to move second piston 58 and force fluid from slave chamber 64. The hydraulic link between second piston 58 and first piston 48 causes first piston 48 to move

so that first rod 49 remains in contact or in close proximity to rocker arm 38 of fuel injection system 36. Piston spring 62 may exert a greater force on second piston 58 than piston spring 52 exerts on first piston 48. Accordingly, second piston 58 will return to its initial position, where end 61 of second rod 59 is separated from valve actuation assembly 32 by distance,  $x$ .

[46]               The shape of cam 40 and cam lobe 42 is adapted to initiate movement of second piston 58 at an advanced timing. In particular, cam 40 and cam lobe 42 are shaped to account for the distance,  $x$ , separating end 61 of rod 59 from valve assembly 32. In other words, cam 40 and cam lobe 42 are shaped to initiate movement of second piston 58 prior to the optimal opening time of engine valve 24. In particular, the adapted shape of cam 40 and cam lobe 42 is selected to initiate movement of second piston 58 at an advanced timing sufficient to take up the excess lash,  $x$ , (for example, 1 mm (0.04 in.) resulting in a desired engine valve 24 movement timing.

[47]               For example, with reference to Fig. 2, line 92 illustrates the relationship between engine crank angle and valve lift height for a lash distance,  $x$ , of approximately 0 mm. As shown, engine valve 24 will begin to move, or lift, approximately  $60^\circ$  before piston 14 reaches a top-dead-center position 100 at the end of a compression stroke. Engine valve 24 will continue to lift as piston 14 moves towards a bottom-dead-center position 102 at the end of the combustion stroke. Engine valve 24 will move towards the first position until valve actuation assembly 32 engages rocker arm 34 to actuate engine valve 24 in a conventional exhaust stroke opening 96. Valve actuation assembly 32 will allow engine valve 24 to return to the first position when piston 14 is at or near the top-dead-center position 104 at the end of the exhaust stroke.

[48]               Line 94 of Fig. 2, illustrates the effect of increasing the lash distance,  $x$ , to approximately 1 mm (0.04 in.). With the increased lash distance,  $x$ , engine valve 24 will start to lift later, approximately  $15^\circ$  before piston 14 approaches the top-dead-center position 100 at the end of the compression stroke.

In addition, the increased lash distance,  $x$ , will result in a lower maximum lift distance of engine valve 24. The above described adapted shape of cam 40 and cam lobe 42 may be selected to compensate for the increased lash distance by propositioning second piston 58, advancing engine valve 24 timing as desired for optimal braking performance.

[49] Adjustment mechanism 65 allows the lash distance,  $x$ , to be varied to optimize the timing of the actuation of engine valve 24. The greatest benefit from an engine braking cycle may be obtained when the exhaust valves 24 are opened to allow the greatest amount of energy in the form of compressed air to escape from combustion chamber 20. This may be accomplished by opening exhaust valves 24 prior to piston 14 reaching top-dead-center position 100 at the end of the compression stroke. The continued opening of exhaust valves 24 will allow a maximum amount of compressed air to escape combustion chamber 20 before piston 14 starts to move towards the bottom-dead-center position of the combustion stroke. One skilled in the art will recognize that the valve actuation timing that provides the greatest engine braking benefit may be determined through testing of engine 10 under various operating conditions.

[50] The lash distance,  $x$ , must also be great enough so that end 61 of second rod 59 does not interfere with the normal operation of valve actuation assembly 32. As one skilled in the art will recognize, engine components may expand in response to the heat generated by the engine 10. Accordingly, lash distance,  $x$ , must be great enough when the engine is cold to avoid interfering with valve actuation assembly 32 when the components expand as engine 10 warms up.

[51] In addition, the lash distance,  $x$ , should be set to limit the maximum lift of engine valves 24. If engine valves 24 are lifted too far, valve elements 25 may engage piston 14 as piston 14 approaches the top-dead-center position at the end of the compression stroke. Any such contact may damage

valve elements 25 and detract from engine performance under standard operating conditions.

[52] As fully described above, the combination of determining and establishing a suitable lash distance,  $x$ , for a particular engine 10, and shaping cam 40 and cam lobe 42 to take up the excess lash when engine braking is activated, results in improved braking performance without the need for a separate de-lash mechanism.

[53] To end the “engine braking” mode when the operating conditions of engine 10 change, control valve 74 is de-energized and allowed to return to the second position. In the second position, fluid is allowed to flow from system 12 through fluid return line 80, thereby breaking the hydraulic link between first and second pistons 48 and 58. The force of piston springs 52 and 62 acts on first and second pistons 48 and 58 to force fluid out of system 12 to return to tank 68. Piston springs 52 and 62 act on first and second pistons 48 and 58 to move first and second rods 49 and 59 away from rocker arms 34 and 38. In this position, first and second rods 49 and 59 will not interfere with either rocker arm 34 or 38 during standard operation of engine 10.

[54] As will be apparent from the foregoing description, the present disclosure provides a system for actuating an engine valve that avoids the need for a de-lash mechanism. The system initiates movement of a slave piston at advanced timing to account for a lash distance that separates a slave piston rod from a valve actuation assembly. The lash distance may be adjusted to optimize the valve actuation timing for a particular engine operating condition. The system of the present disclosure will therefore provide for improved control over an auxiliary valve actuation system that implements a variation on conventional valve actuation timing.

[55] It will be apparent to those skilled in the art that various modifications and variations can be made in the system of the present invention without departing from the scope of the disclosure. Other embodiments of the

system will be apparent to those skilled in the art from consideration of the specification and practice of the valve actuator disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope of the disclosure being indicated by the following claims and their equivalents.